Leaf hydraulics: implications for understanding leaf structure and function, drought resistance and community assembly

By

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The research associated with this thesis abides by the international and Australian codes on human and animal experimentation, the guidelines by the Australian Government's Office of the Gene Technology Regulator and the rulings of the Safety, Ethics and Institutional Biosafety Committees of the University.

Abstract

The leaf hydraulic system in plants is charged with supplying water to the sites of evaporation in order to facilitate photosynthesis and growth, while simultaneously resisting negative pressure generated under tension induced by water stress. These processes contribute substantially to the enormous variation in leaf structure and function found across vascular plants and may contribute in fundamental ways to plant function and differences in species ecological strategy.

In this dissertation I examined the leaf hydraulic properties of a phylogenetically, morphologically and ecologically diverse group of woody angiosperm species in order to better understand how leaf hydraulics defines plant function under drought, is integrated with leaf structure and function, and drives differences in species ecological strategy and drought resistance. My results strongly indicate that leaf hydraulics underlie many important aspects of plant function and leaf structure. They also enhance our understanding of the function and assembly of ecological communities, as well as the evolution of plant drought resistance. Furthermore, they provide a potentially crucial tool for predicting the potential impacts of climate change and increasing aridity on plant function and community dynamics.

In drought-stressed seedlings, the recovery of gas exchange following re-watering was strongly correlated with the relatively slow recovery of leaf hydraulic conductance (K_{leaf}) in three ecologically disparate species. This hydraulic-stomatal limitation model of gas exchange recovery observed in these species indicates that leaf hydraulics is a key driver of plant functional recovery from drought. Variation in the hydraulic vulnerability of leaves to water-stress-induced tension ($P50_{\mathrm{leaf}}$) was intimately linked to drought survival in the experimental species. Furthermore, variation in $P50_{\mathrm{leaf}}$ across a larger group of species was significantly correlated with a suite of leaf structural and functional traits that confer increased drought resistance.

As expected, K_{leaf} was positively correlated with both maximum assimilation and vein density across species. Thus, the water transport capacity of leaves may constrain plant gas exchange and reflect leaf hydraulic design. In addition, insights into the water transport pathway in leaves were generated by different measures of leaf capacitance (C_{leaf}) related to short and long-term fluctuations in transpiration.

Variation in leaf hydraulic vulnerability was strongly correlated with the xylem dimensions in the leaf minor veins that predict the vulnerability of conduits to collapse under negative pressure ($(t/b)^3$) . While this result does not necessarily indicate a direct link between hydraulic dysfunction and conduit collapse, the relationship between $P50_{\mathrm{leaf}}$ and $(t/b)^3$ suggests evolved coordination in leaves between xylem structural strength and hydraulic vulnerability that will have major implications for understanding leaf-carbon economy.

Leaf hydraulic vulnerability was also shown to define the bioclimatic limits of species. Species with low $P50_{\mathrm{leaf}}$ extended into drier regions, while species with high $P50_{\mathrm{leaf}}$ were restricted to areas of high rainfall. Furthermore, the adaptive significance of $P50_{\mathrm{leaf}}$ was demonstrated using phylogenetically independent comparisons of species pairs from wet and dry forests. Across these pairings, wet forest species were consistently more vulnerable to water-stress-induced hydraulic dysfunction, despite their generic ecological affinity in both wet and dry forests. This indicates that the evolution of leaf hydraulic vulnerability is bi-directional and adaptive across the rainfall spectrum.

Despite the adaptive significance of leaf hydraulic vulnerability, within-site variability in $P50_{\mathrm{leaf}}$ differed between two high-rainfall communities that contrast in species diversity and historical ecology. This suggests that the functional composition of modern-day plant communities are not only influenced by current climate but by processes related to long-term climate variability and/or parochial historical constraints.

This detailed examination of leaf hydraulics in woody angiosperms provides key insights into the nature of leaf structure and function and enhances our understanding of the processes that drive plant responses to environmental stress and determine differences in species ecological strategy. Greater understanding of the hydraulic constraints in leaves across different plant groups will therefore lead to better management practices in natural and agricultural systems.

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Table of contents